Update on DVCS

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EIC Task Force meeting

BNL – Nov. 3rd, 2011

MILOU

Written by E. Perez, L Schoeffel, L. Favart [arXiv:hep-ph/0411389v1]

The code MILOU is Based on a GPDs convolution model by:
A. Freund and M. McDermott [All ref.s in: http://durpdg.dur.ac.uk/hepdata/dvcs.html]

- ✓GPDs, evolved at NLO by an indipendent code which provides tables of CFF
  - at LO, the CFFs are just a convolution of GPDs:

$$\mathscr{H}(\xi,Q^2,t) = \sum_{u,d,s} \int_{-1}^{1} \left[\frac{e_i^2}{1-x/\xi - i\varepsilon} \pm \{\xi \to -\xi\} \right] H_i\left(x,\xi,Q^2,t\right)dx$$

- ✓provide the real and imaginary parts of Compton form factors (CFFs), used to calculate cross sections for DVCS and DVCS-BH interference.

$$\frac{d\sigma}{dxdyd\,|\,t\,|\,d\phi d\varphi} = \frac{\alpha^3 x_B y}{16\pi^2 Q^2 \sqrt{1+\varepsilon^2}} \left|\frac{\mathcal{I}}{e^3}\right|$$

$$\phi = \phi_N - \phi_l$$

$$\varphi = \Phi_T - \phi_N$$

$$\varepsilon \equiv 2x\frac{m_N}{Q}$$

$$\left|\mathcal{I}_{\mathcal{BH}}\right|^2 = \frac{e^6}{x^2 y^2 (1+\varepsilon^2)^2 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{BH} + \sum_{n=1}^{2} c_n^{BH}\cos(n\phi) + s_1^{BH}\sin(\phi) \right\}$$

$$\left|\mathcal{I}_{\mathcal{DVCS}}\right|^2 = \frac{e^6}{y^2 Q^2} \left\{ c_0^{DVCS} + \sum_{n=1}^{2} \left[c_n^{DVCS}\cos(n\phi) + s_n^{DVCS}\sin(n\phi) \right] \right\}$$

$$\left|\mathcal{I}\right|^2 = \frac{\pm e^6}{xy^3 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{I} + \sum_{n=1}^{3} c_n^{I}\cos(n\phi) + s_1^{I}\sin(\phi) \right\}$$

- ✓ $\frac{d\sigma}{d|t|} = \exp\left(B\left(Q^2\right)t\right)$ -> The B slope is allowed to be costant or to vary with Q^2:
- ✓Proton dissociation ($ep \to e\,\gamma\,Y$) can be included
- ✓Other non-GPD based models are implemented like FFS, DD

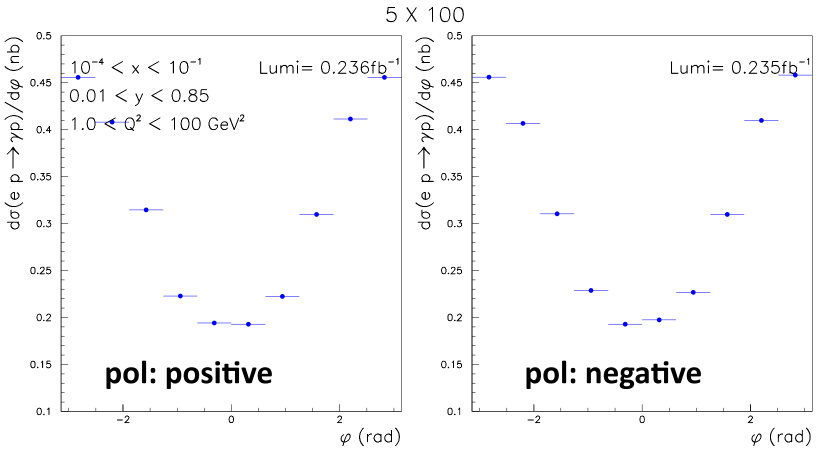
Summary from July 21st

- Uncertainties for low |t| values will be dominated by systematics, the use of RP is convenient
- Differential xsec at large |t| values can also be measured with good accuracy, this requires years of data taking. The use of the main detector for measuring |t| from momentum conservation is the best option
- BCA can also be measured in bins of Q^2 and x, it is complementary to the |t| xsec, it required positron beam even with lower lumi

Outlook:

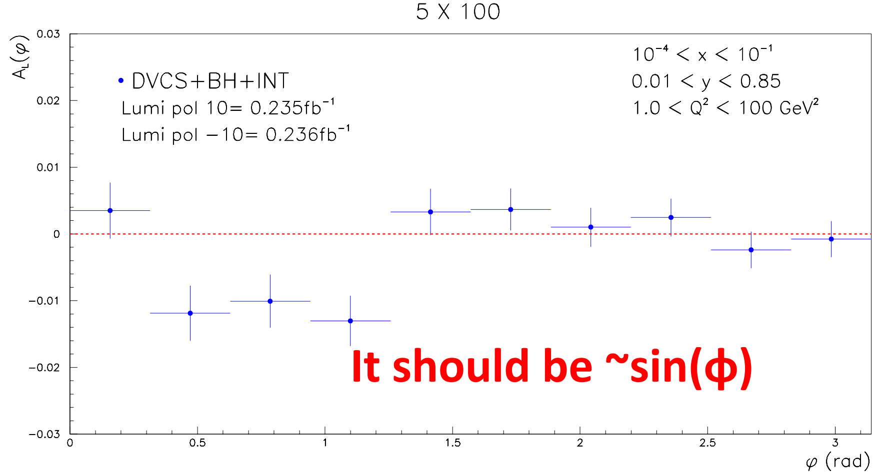
- Better Understand the implementation of the beam-helicity effects in the code
- Smear the distributions -> see Mike talk

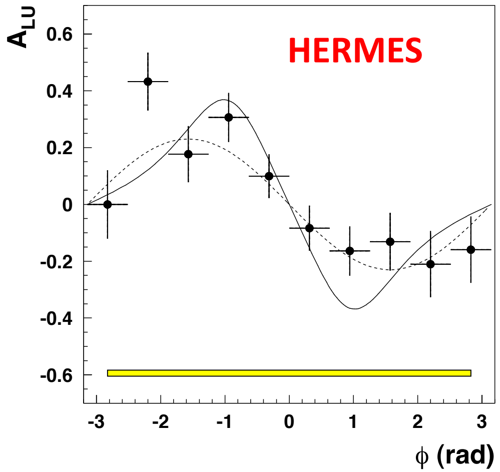
Longitudinal beam-helicity asymmetry (a.o. July)



Pol. electrons: long. or anti-long.

Pol. protons: 0





Asymmetry appears much smaller than expected

Checking the MC code…

INT DVCS

$$A_{LU}(\varphi, e_l) = \frac{\frac{d\sigma^{\rightarrow}}{d|\phi|} - \frac{d\sigma^{\leftarrow}}{d|\phi|}}{\frac{d\sigma^{\rightarrow}}{d|\phi|} + \frac{d\sigma^{\leftarrow}}{d|\phi|}} = \frac{-e_\ell \frac{K_{\rm I}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left[\sum_{n=1}^{2} s_n^{\rm I}\sin(n\phi)\right] + \frac{1}{Q^2} s_1^{\rm DVCS}\sin\phi}{\frac{1}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left[K_{\rm BH}\sum_{n=0}^{2} c_n^{\rm BH}\cos(n\phi) - e_\ell K_{\rm I}\sum_{n=0}^{3} c_n^{\rm I}\cos(n\phi)\right] + \frac{1}{Q^2}\sum_{n=0}^{2} c_n^{\rm DVCS}\cos(n\phi)}$$

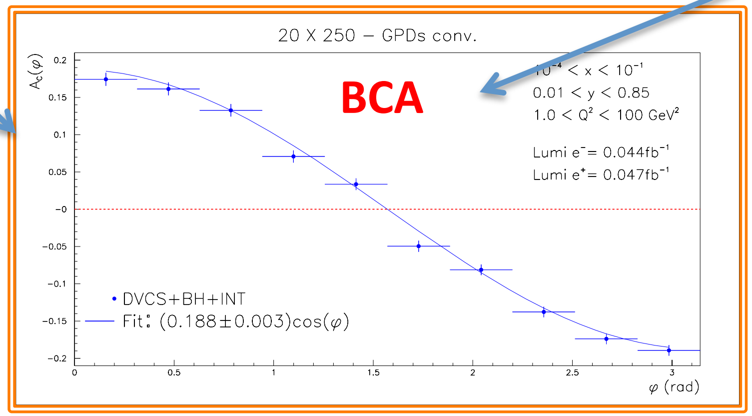
The INT term can be disentangled by the beam charge-spin asymmetry

Longitudinal beam-helicity asymmetry

The problem observed in July for the SSA was due to a bug, not in the main code from F and McD, where I long hunted for it, but in a subroutine of the H1 people's implementation

```
 if (ipro.eq.4)
+ resu = (res(4)+res(2))*
+ (1+0.2*(-1.D0*SIGN)*DCOS(phi_newcalc_0))
ccc print *,SIGN
ccc if (ipro.eq.4) resu = res(7) ! CA without TW3
```

Actually at ipro4, which is the option for SSA, does not correspond the call to the correct result from the code (it was commented. Morover the BCA dependence was replaced with a nice parameterization (this explains the nice dependence observed earlier for mock data in BCA)



New data generation for the SSA is ongoing… probably ready by next week

Bug-fixing as of July 21st

new version of MILOU now on on AFS.
Instructions on the code and its output files are on the wiki page:
https://wiki.bnl.gov/eic/index.php/MILOU

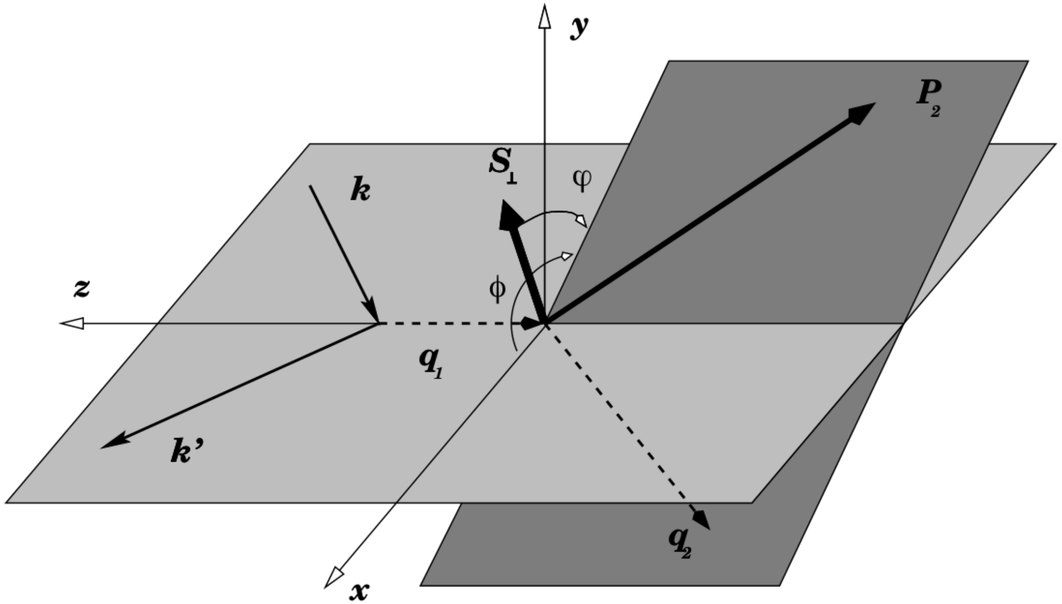
List of improvements a.r.o. the original version:

1) **Fixed the FORTRAN common blokes:** they where rewritten by bases and did not preserve the random seed as set in the cards. That caused one had to recalculate the integral every generation (which take days). Now the integral can be calculated ones per energy conf. and the same grid used for each generation.

2) **Corrected ALLM parameterization for F2 implemented (relevant when running in FFS-model mode)**. this caused a disagreement between the GPD and the FFSs models of a factor two or more in the cross sections even at HERA energies. The correct ALLM is taken from the original ALLM paper hep-ph/9712415v2, so the agreement between the two models at HERA energies and with the predictions from the GenDVCS Monte Carlo (also using FFS and used by the ZEUS Collaboration) it is now satisfactory.

3) **The output is not not only in the form of a PAW ntuple but the code creates a text file in the Pythia-like ascii format**, in the same standard of other MCs for EIC. Output description is on the web-page.

Transverse target-spin asymmetry



Transverse Target-Spin Asymmetry

$\phi = \phi_N - \phi_l$ — **Angle btw the production and scattering planes**

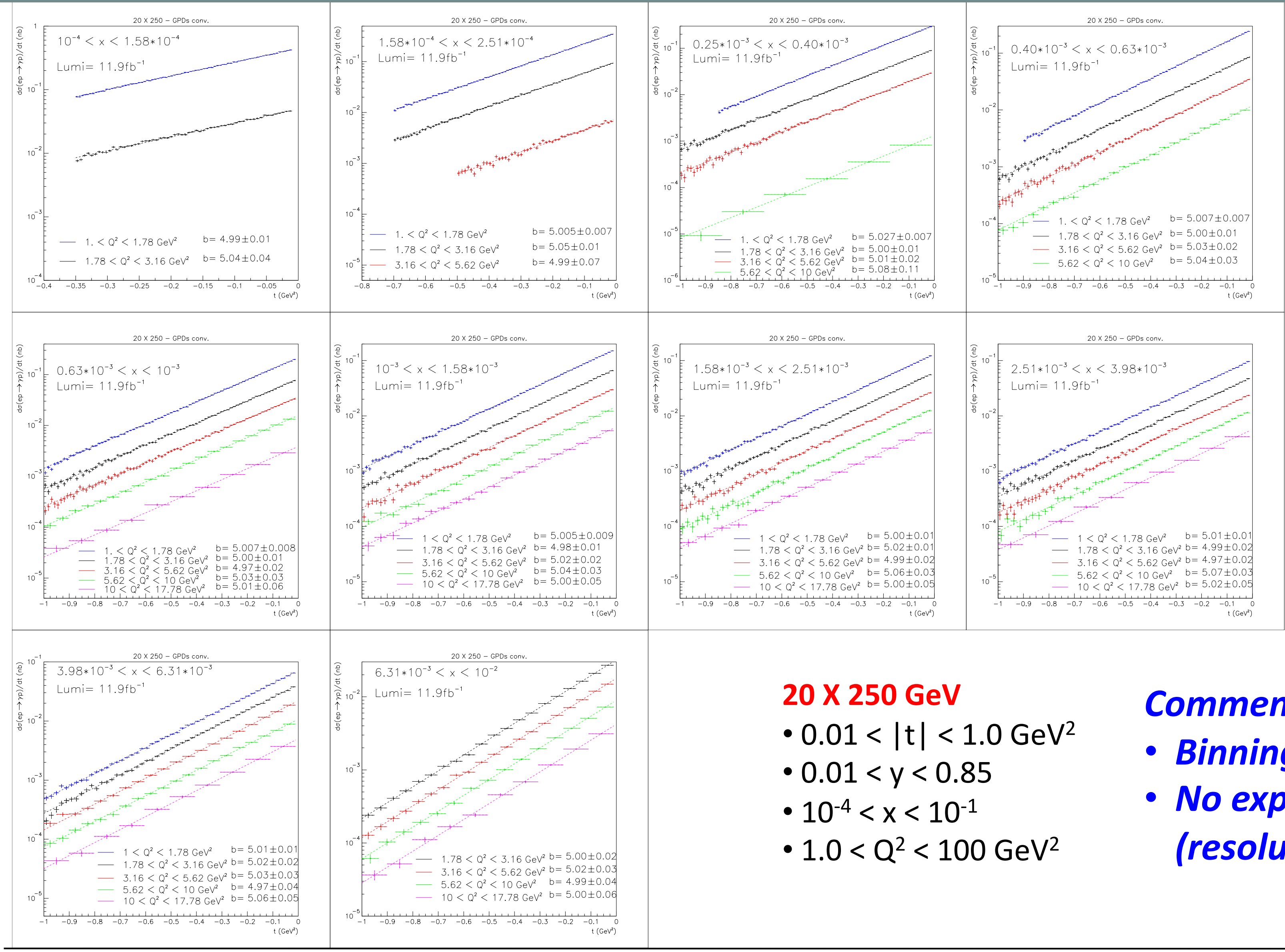
$\varphi = \Phi_T - \phi_N$ — **Angle btw the scattering plane and the transverse pol. vector**

MILOU does not include a transverse polarization of the beams

The trick to show the impact of an EIC on such a measurement we used is to simulate event distributions as a function of ϕ considering 80% polarization and half statistics for each spin configuration. This led to zero values measurement (since TSA is missing in the code) but with realistic statistical uncertainties porportional to φ. (See. Dieter's talk)

Statistical uncertainties → *For each bin in Q2 and x* → **D. Mueller** → **Superimposed to theory curves to show the discriminatory impact of an EIC**

|t|-differential x-sec: low |t| - As of July

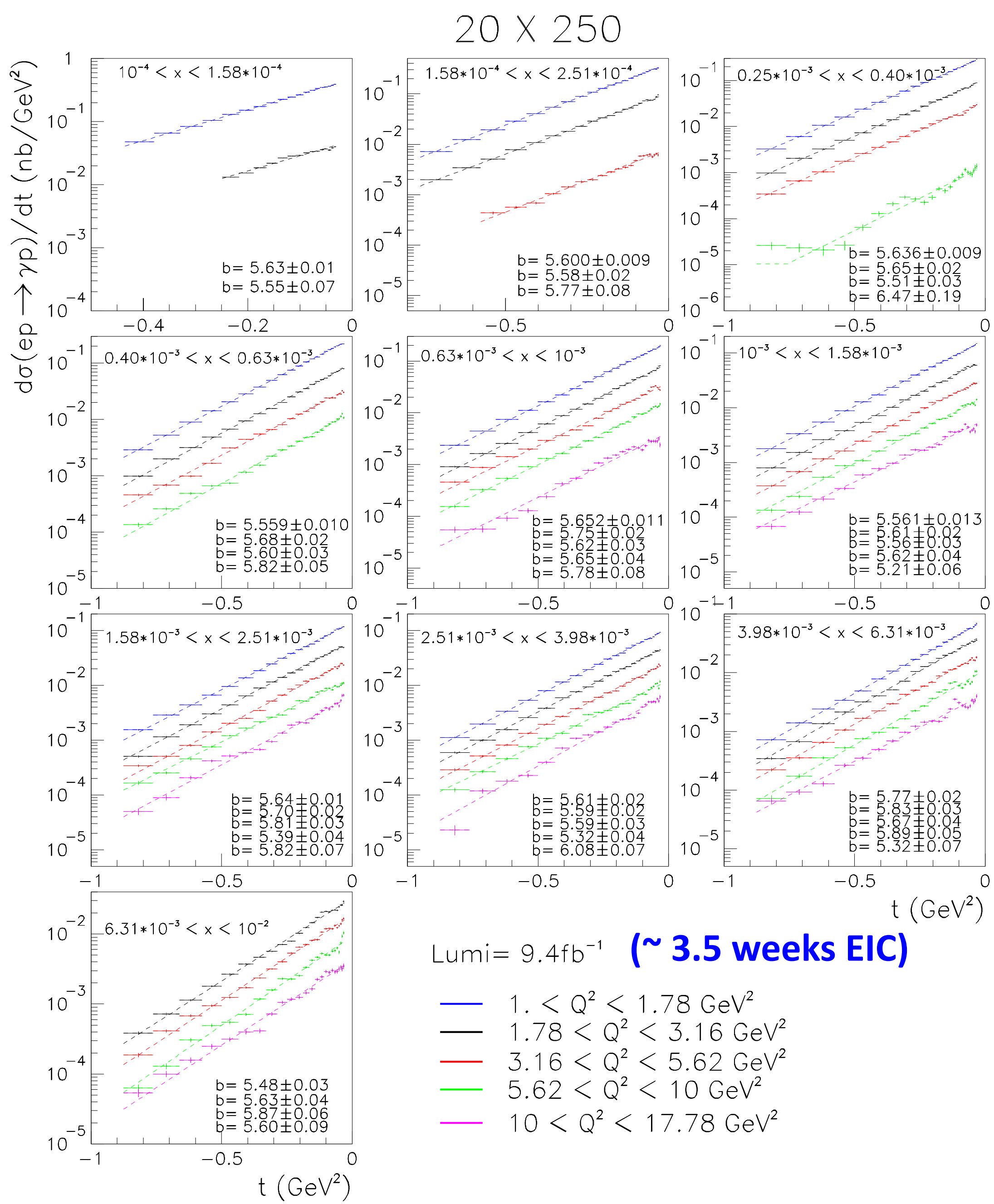


20 X 250 GeV

- $0.01 < |t| < 1.0$ GeV^2
- $0.01 < y < 0.85$
- $10^{-4} < x < 10^{-1}$
- $1.0 < Q^2 < 100$ GeV^2

Comments:

- ***Binning is unrealistic***
- ***No experimetal (resolution) effect***



|t|-differential x-sec

$$\frac{d\sigma}{d|t|} = \frac{\#\,evt}{\Delta_{bin} \bullet \mathcal{L}} \qquad \sim e^{-bt}$$

b=5.6

Differences as of July:

- **It uses smeared t values (ZEUS with RP)**
- **The binning is now not uniform (3*reso)**
- **The b slope 5.0 -> 5.6 compatible with H1 data, to facilitate Dieter's global fitting**

e-p x-secs — *FLUX factor* → **γ*-p x-secs**

Mock data — *D. Mueller's global fits* → **GPD H**

. (See. Dieter's talk)

Few thoughts on the systematics

To understand the systematic before having a full detector simulation and even knowing sub-detector specifications it is simply not realistic.

Nevertheless, to have a quantitative idea of the order one can expect, I looked at the ZEUS DVCS-analysis (using Roman Pots). Here are their main sources of systematics:

- Beam-halo, (E+Pz+2Pz(RP)<1860 GeV → only 3% bkd survives (negligible @ ZEUS)
- t resolution → bin properly, accordingly to resolution.
- X coordinate in RP → this syst. Was due to an inaccurate simulation of the RP detectors.
- Minimum approach of the track to the beam-pipe

TOTAL = 8%

- LUMI (2.25%) → does not affect the t-slope

$\pi^0 \rightarrow \gamma\gamma$ was found negligible (@ HERA but @ eRHIC?)

For the moment, for the purpose of fits using pseudo-data, we'll be using a realistic value of 5%

Summary

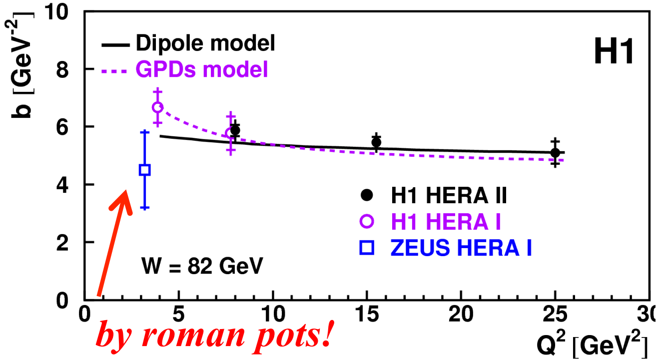
- The spin asymmetry code problem has been fixed
- We have a way to show the grate potential of an eRHIC to transverse target-spin asymmetries
- The differential cross-sections now are simulated using a smeared variable and with a 3*reso binning
- Systematics can reasonably considered in the order of 5%
- Mock data have been used for global fits with the existing HERA data to extrapolate GPDs, the impact of an eRHIC on the present knowledge can be huge even after a moth of data taking at the 20x250 energy configuration.

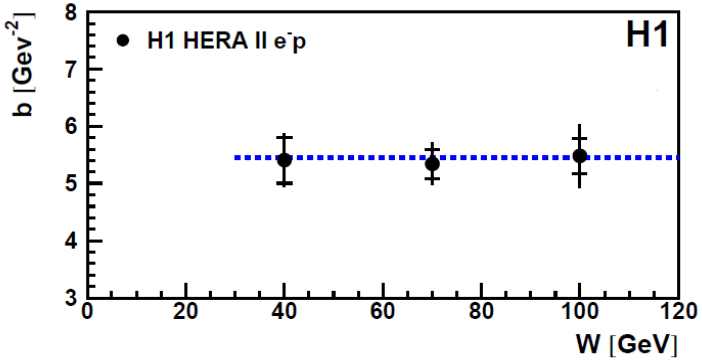
Outlook:

- ✧ Simulate the longitudinal spin-asymmetries (hopefully by next week)
- ✧ Scan also the 5x100 GeV energy configuration

Back up

Scanning the phase space…

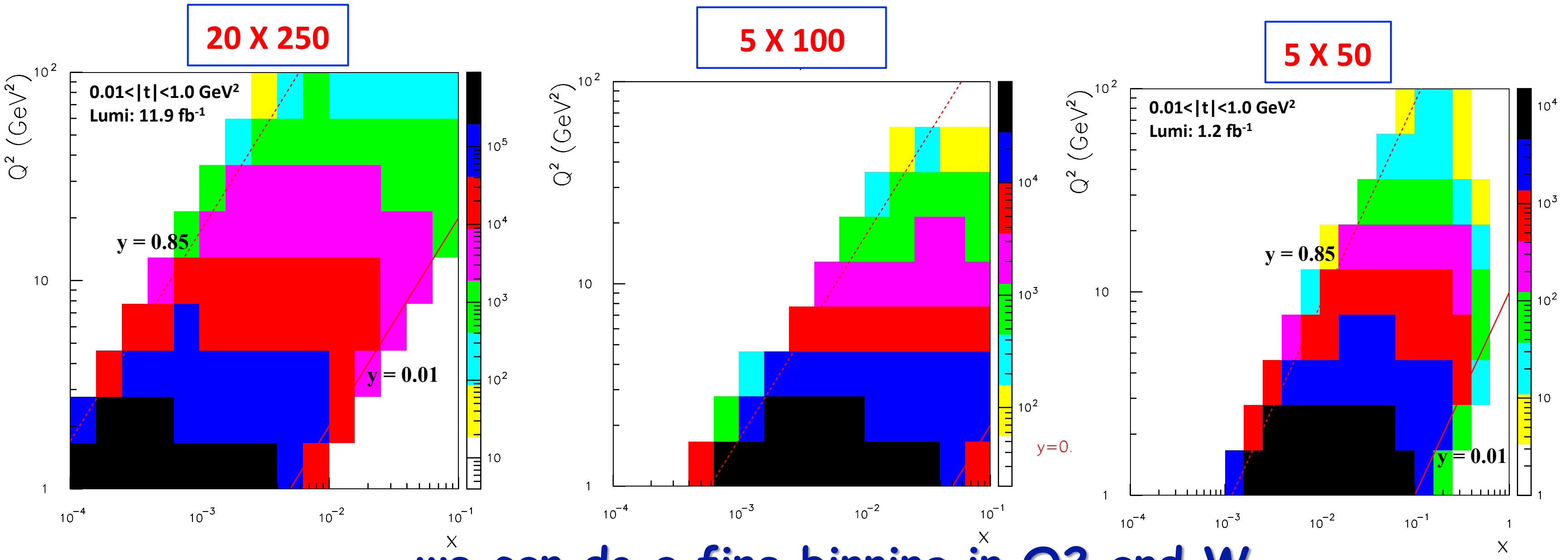




EIC lumi:
11.6 fb^{-1}/month @ 20x250

- ✧ **EIC will provide sufficient luminosity to bin in multi-dimensions**
- ✧ **wide x and Q^2 range needed to extract GPDs**

Logarithmic bins: $1 < Q^2 < 100$ GeV^2
$10^{-4} < x < 0.1$



… we can do a fine binning in Q2 and W

|t|-differential cross section

$0.01 < |t| < 1.0$ GeV^2

- Precision enormously improved a.r.o. present (mostly below 1%)
- Systematics will dominate!
- Mostly within Roman pots acceptance ($|t|>0.06$ GeV^2),

i.e. RP @ ZEUS:
Resolution LPS: Pt=5 MeV -> $|t|=10^{-2}$Pt

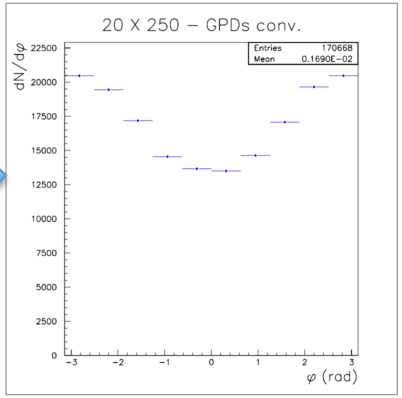
$1.0 < |t| < 2.0$ GeV^2

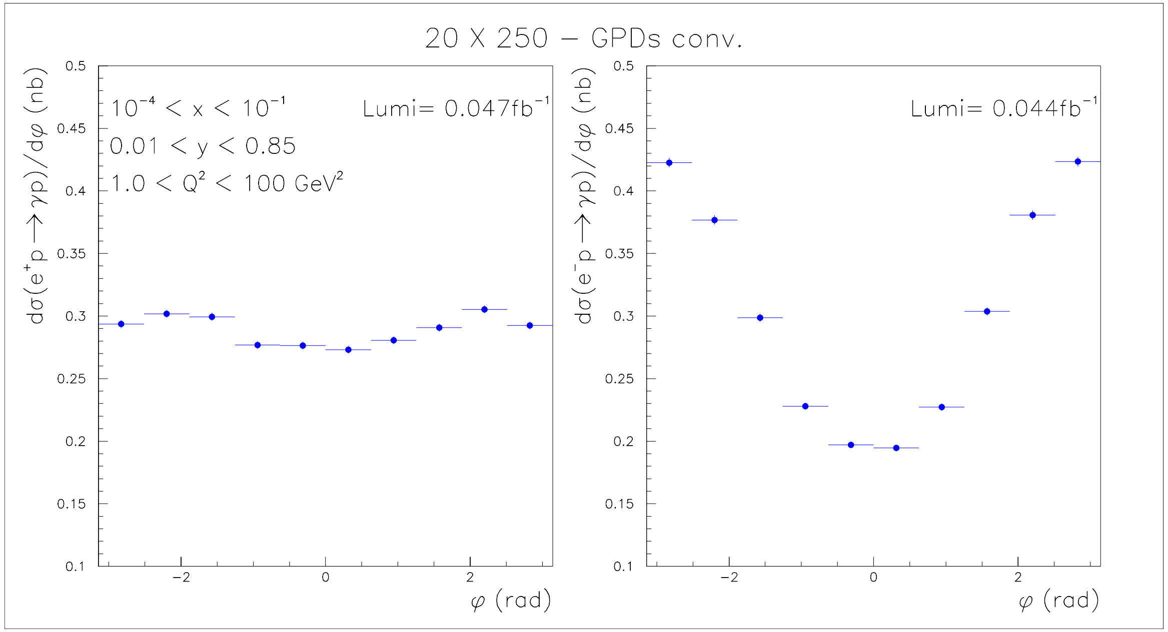
- Xsec drops drastically
- eRHIC still allows for good binned measurements after years of data taking
- Main detector can be used for measuring |t| from momentum conservation.

Beam Charge Asymmetry

A data sample including DVCS + BH + Int has been generated for the configuration 20 X 250 for electrons and positrons beams separately

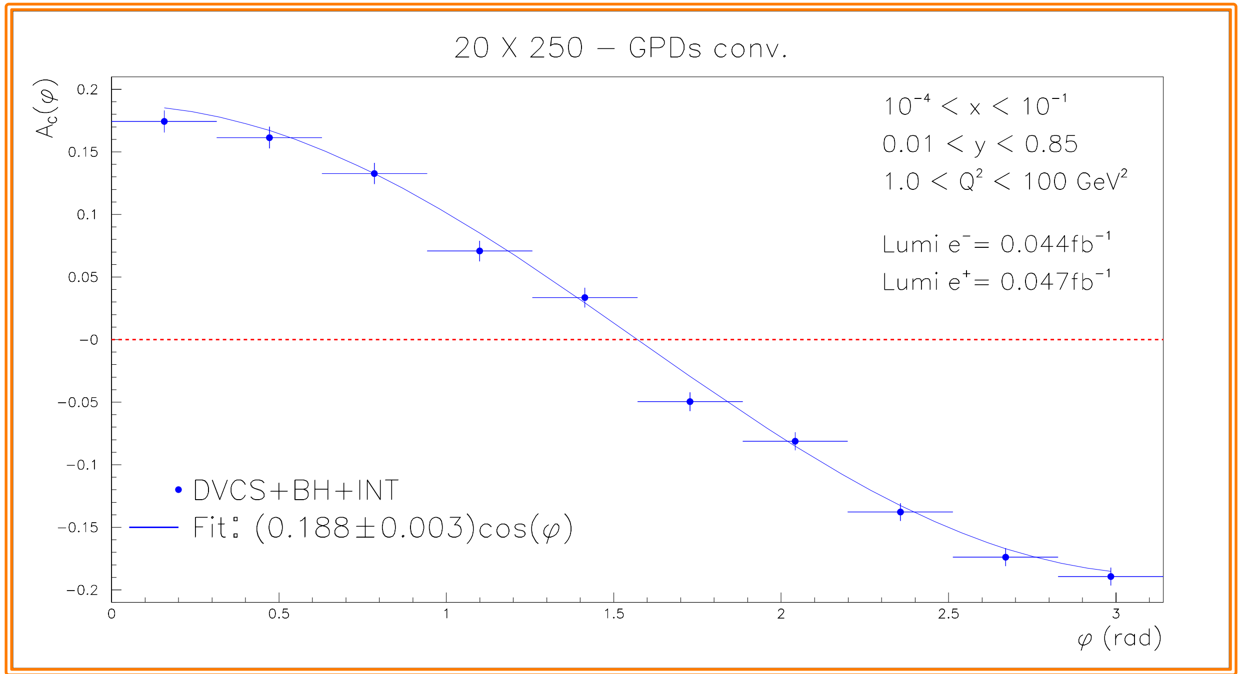
Lumi-ele: 44 pb^{-1}
Lumi-pos: 47 pb^{-1}

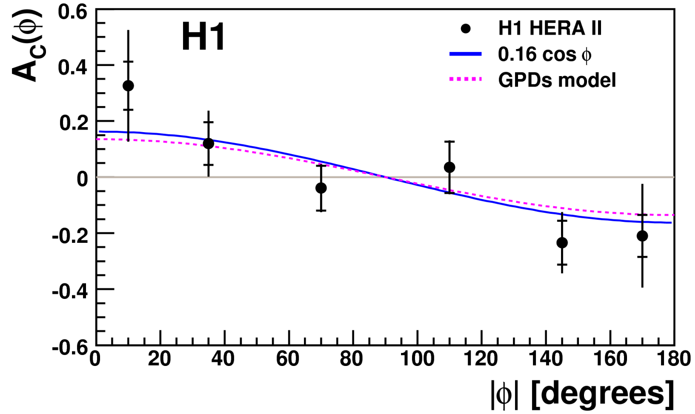


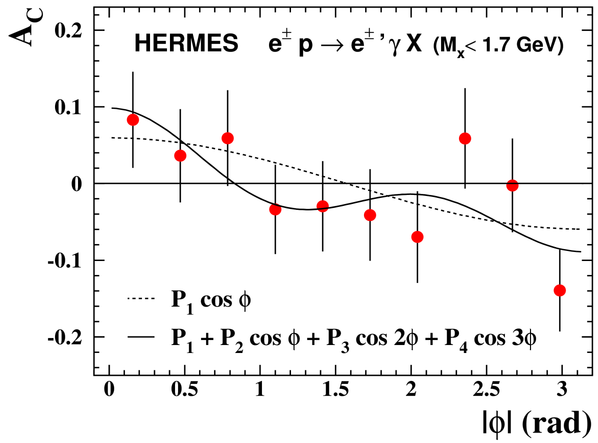


For both electrons and positrons the differential xsec vs ϕ has been extracted

Beam Charge Asymmetry



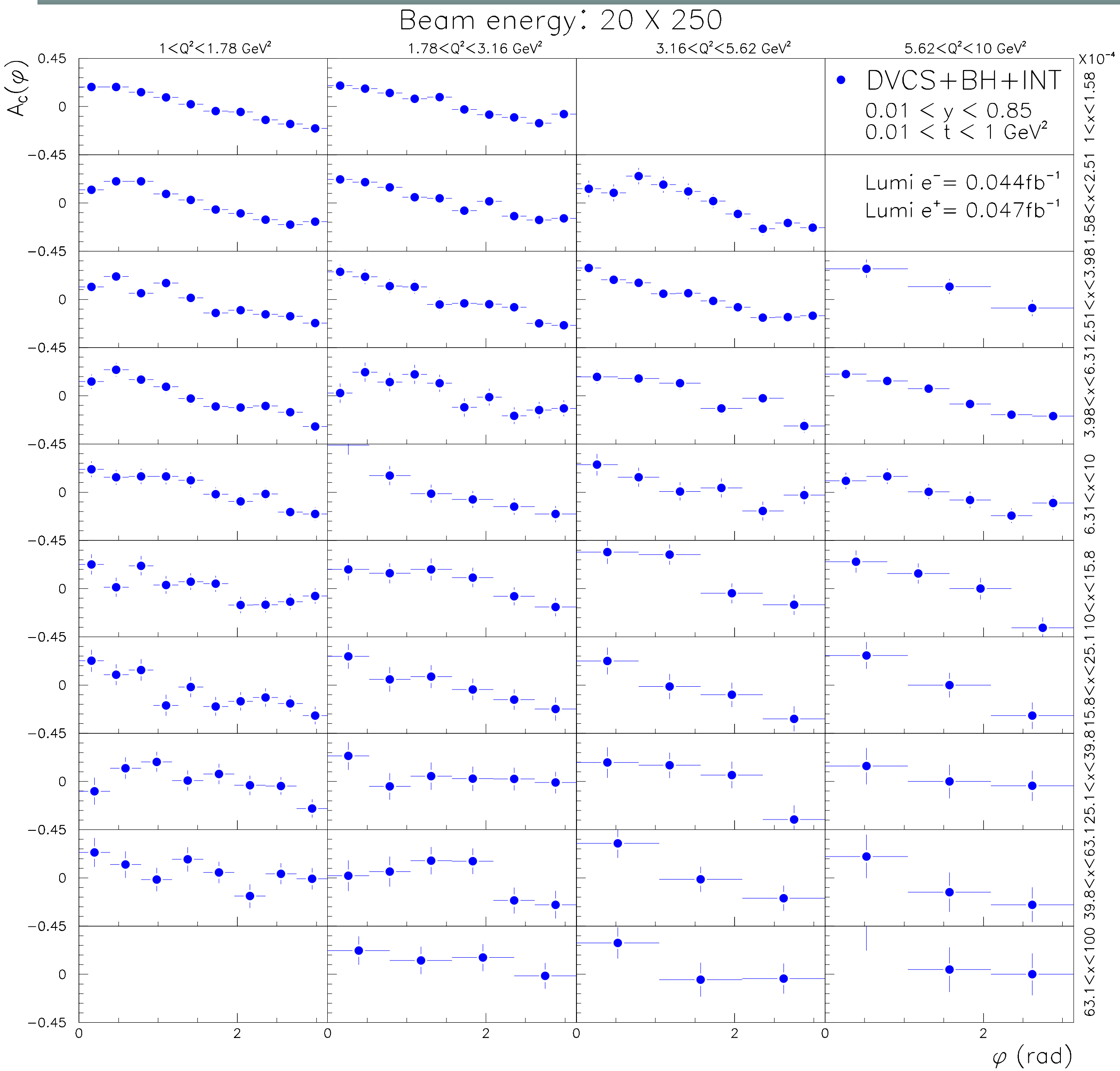




$$A_C = \frac{\frac{d\sigma^+}{d|\phi|} - \frac{d\sigma^-}{d|\phi|}}{\frac{d\sigma^+}{d|\phi|} + \frac{d\sigma^-}{d|\phi|}} = p_1 \cos(\phi) = 2A_{BH} \frac{\mathrm{Re}\, A_{DVCS}}{|A_{DVCS}|^2 + |A_{BH}|^2} \cos(\phi)$$

Excellent measurement with a modest beam-time. Accurate measurements in bins of Q^2 and x are possible! **(Simulating more samples…)**

Beam Charge Asymmetry



$10^{-4}<x<1.58x10^{-4}$

$1.58x10^{-4}<x<2.51x10^{-4}$

$2.51x10^{-4}<x<3.98x10^{-4}$

$3.98x10^{-4}<x<6.31x10^{-4}$

$6.31x10^{-4}<x<10^{-3}$

$10^{-3}<x<1.58x10^{-3}$

$1.58x10^{-3}<x<2.51x10^{-3}$

$2.51x10^{-3}<x<3.98x10^{-3}$

$3.98x10^{-3}<x<6.31x10^{-3}$

$6.31x10^{-3}<x<10^{-2}$

DVCS: the beam-charge asymmetry

$$|A|^2 = |A_{DVCS}|^2 + |A_{BH}|^2 + |A_I|^2$$

DVCS and BH: identical final state → they Interfere

Interference term: $A_I \propto Re(A_{DVCS}) + Im(A_{DVCS})$

$|A_{BH}|$ is well known

Beam charge asymmetry:

$$A_C = \frac{\frac{d\sigma^+}{d|\phi|} - \frac{d\sigma^-}{d|\phi|}}{\frac{d\sigma^+}{d|\phi|} + \frac{d\sigma^-}{d|\phi|}} = p_1 \cos(\phi) = 2A_{BH} \frac{\mathrm{Re}\, A_{DVCS}}{|A_{DVCS}|^2 + |A_{BH}|^2} \cos(\phi)$$

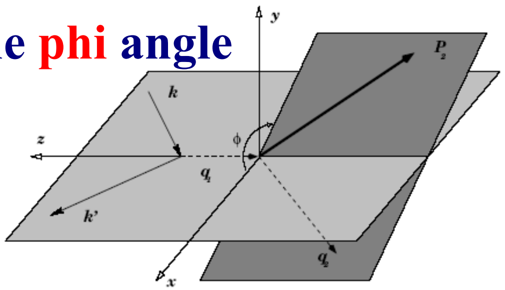
Beam charge-helicity asymmetry: ~ interacion term

|t|-slope: $e^{-b|t|} \Rightarrow \sigma_{DVCS} = |A_{DVCS}|^2 / 16\pi b$

The ratio between the real and imaginary parts of the DVCS amplitude can be extracted:

$$\rho = \frac{\mathrm{Re}\, A_{DVCS}}{\mathrm{Im}\, A_{DVCS}}$$

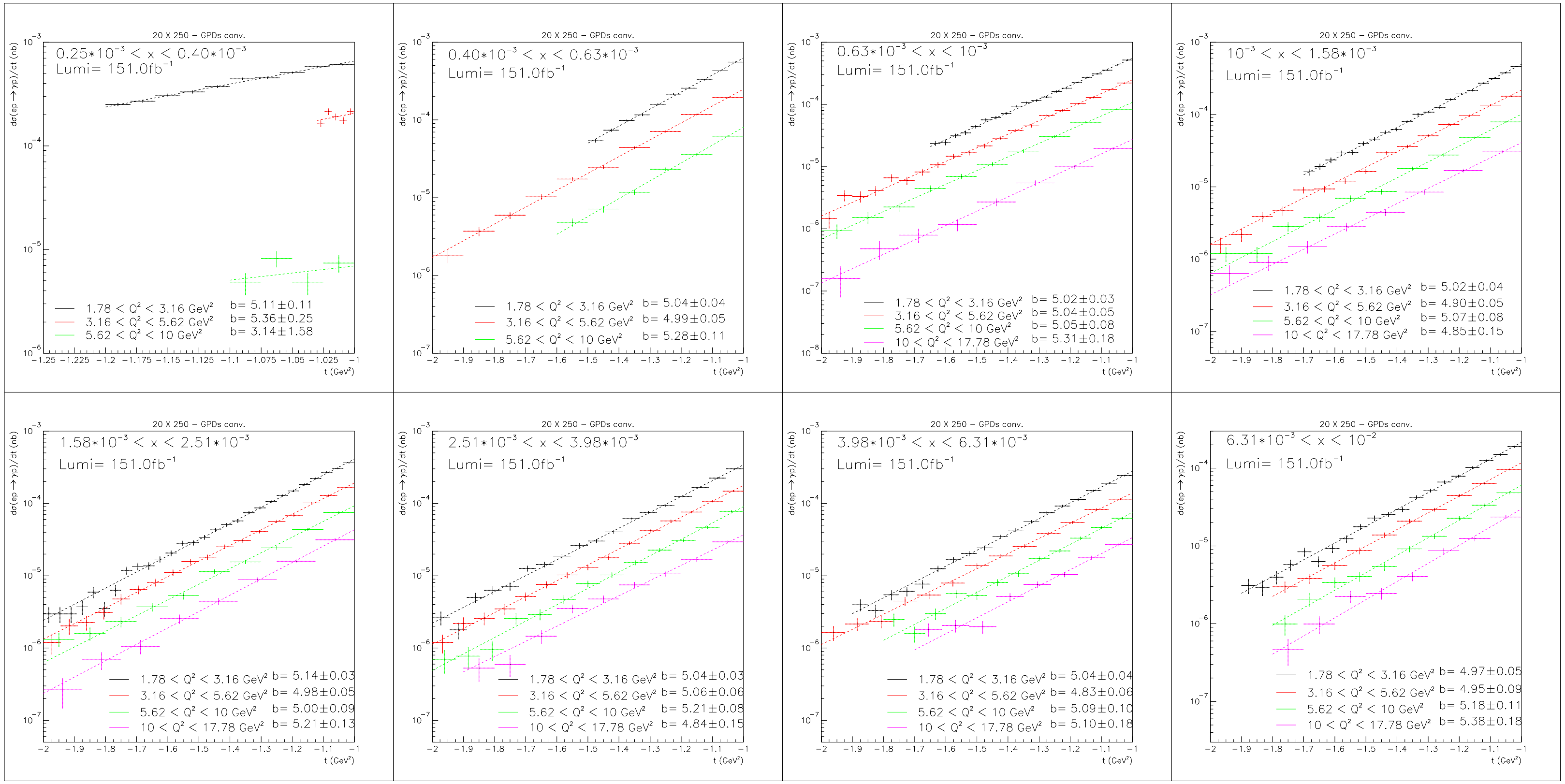
The phi angle



At EIC:

Possible with a positron beam, thanks to a good tracker coverage

|t|-differential cross section: high |t|



$1.0 < |t| < 2.0$ GeV^2

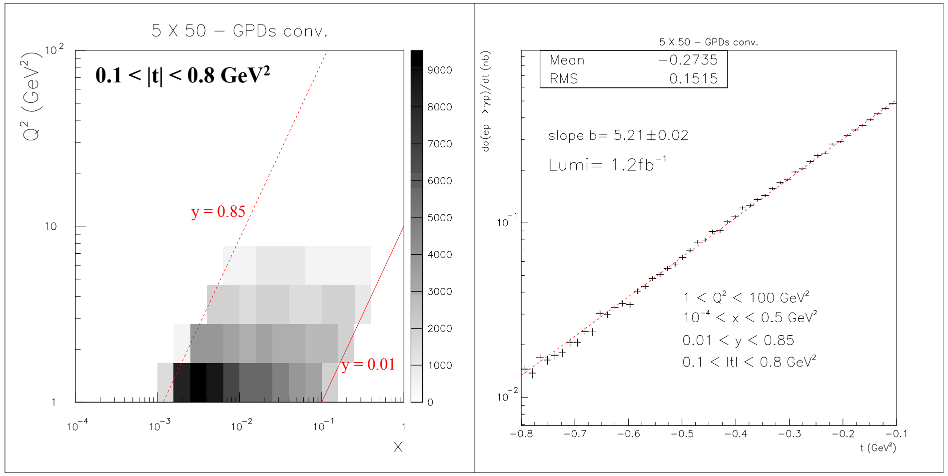
300k DVCS events simulated
L: 151 fb^{-1} (~ 52 weeks EIC)

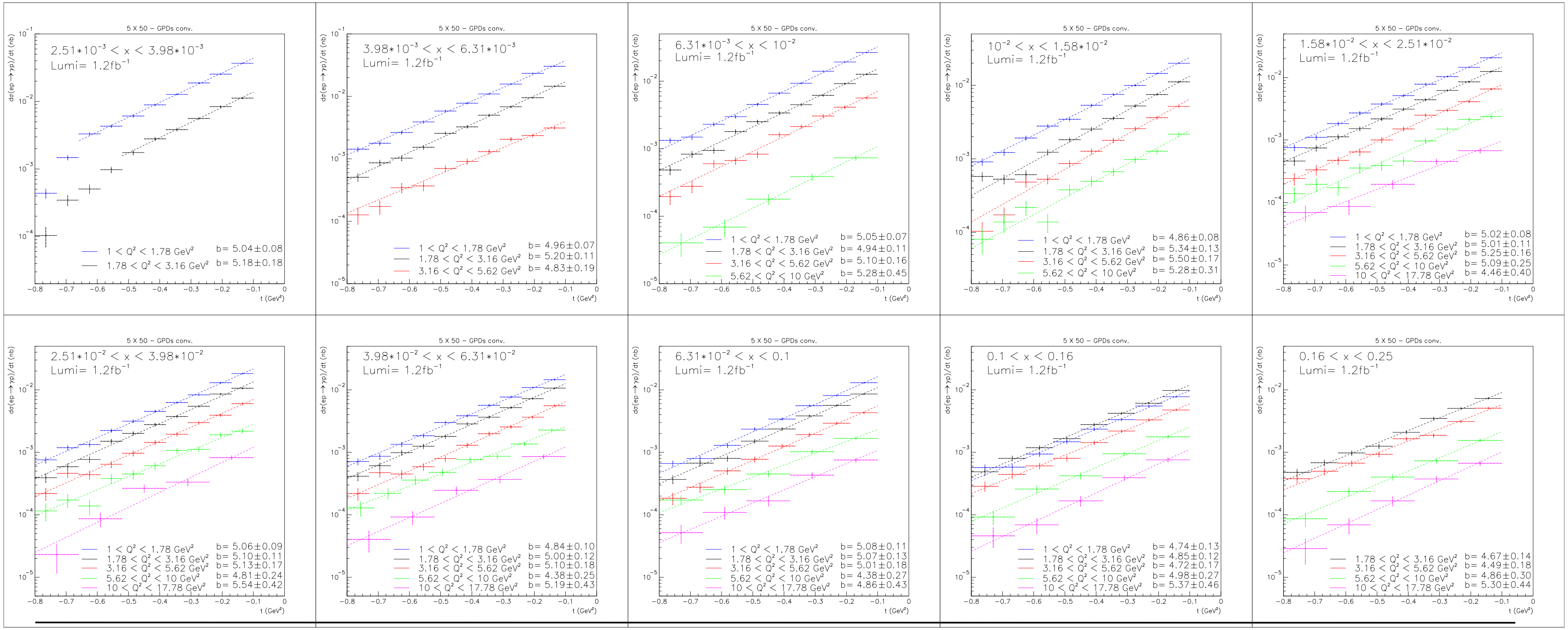
eRHIC can provide precise measurement of the |t|-slope even at large |t| values… but this may require years of data taking

5 X 50

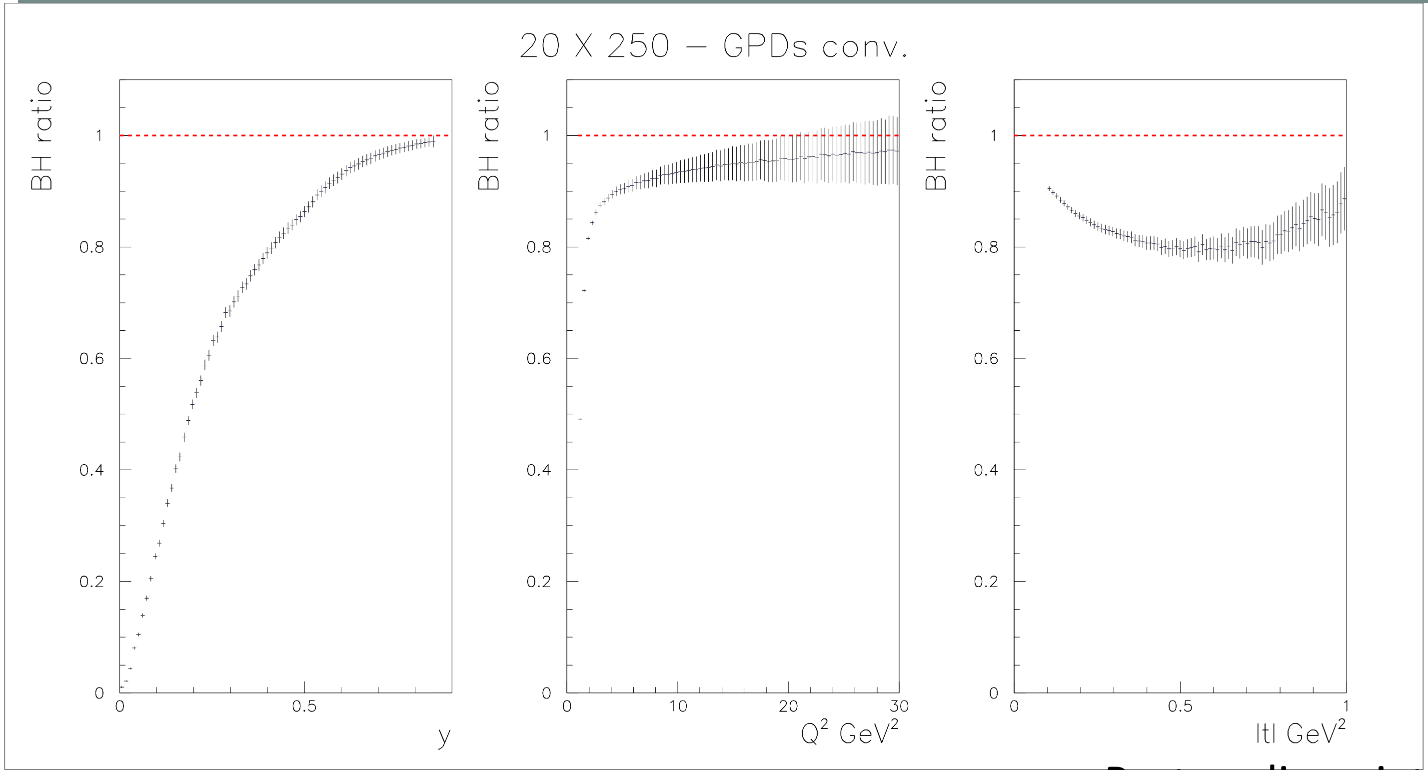
Lumi: 1.2 fb^{-1} (~ 1 week EIC)

$$\frac{d\sigma}{d|t|} = \frac{\# evt}{\Delta_{bin} \bullet \mathcal{L}}$$





Fraction of Bethe-Heitler



$1.0 < Q^2 < 100$ GeV^2
$0.01 < y < 0.85$
$0.1 < |t| < 1.0$ GeV^2

DVCS and BH samples normalized at Lumi

$$frac(BH) = \frac{BH_{evt}}{BH_{evt} + DVCS_{evt}}$$

BH generated sample much smaller than DVCS one -> error bars

- Proton dissociation not included for both DVCS and BH (but mostly process independent…)
- BH dominates at large y (as expected!)
- Part of BH will be removed by DVCS selection criteria for a DVCS enhanced sample (interference term not affected)